Home Heating and Asthma in New Zealand

A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Commerce in Economics in the University of Canterbury

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Abstract

New Zealand has one of the highest asthma prevalence rates among developed countries and previous research attributes this partly to poor socioeconomic conditions and to insufficient home heating in particular. Retrospective empirical studies from overseas suggest that home heating is associated with asthma rates. However, the evidence to date is not conclusive. In this thesis, I present a theoretical framework and empirically investigate the link between home heating and asthma hospital admissions in New Zealand using panel data techniques and controlling for endogeneity. The hypothesis that higher electricity prices (via less adequate heating) increase asthma admissions is tested and receives strong empirical support across a number of model specifications and datasets used.

Glossary *(alphabetical)*

CPI – Consumer Price Index

DHB – District Health Board

EECA – Energy Efficiency and Conservation Authority

HDM – House Dust Mites

HVDC – High Voltage Direct Current

IV – Instrumental Variable

NZGSS – New Zealand General Social Survey

PCSE - Panel-Corrected Standard Errors

Q1 - Quarter 1 (January-March)

Q2 - Quarter 2 (April-June)

Q3 – Quarter 3 (July-September)

Q4 – Quarter 4 (October-December)

QSDEP - Quarterly Survey of Domestic Electricity Prices

TSLS – Two Stage Least Squares

1. Introduction

New Zealand has one of the highest asthma prevalence rates among developed countries and previous research attributes this partly to poor socioeconomic conditions in certain neighbourhoods (or among certain ethnic groups) and to insufficient home heating in particular (Ellison-Loschmann et al, 2004; Petronella and Conboy-Ellis, 2003; Butler et al, 2003; and Crane et al, 1998).

Retrospective empirical studies from overseas suggest that the lack of home heating is associated with higher asthma rates (e.g., see Borooah (2007) for recent evidence from Ireland) and a limited number of randomized controlled trials seem to support this hypothesis (Barton et al, 2007). However, the evidence to date is not conclusive, many of the studies available do not control adequately for the endogeneity of home heating, and rigorous analyses of New Zealand asthma data are sparse. A careful local study which would provide inputs into government's decision-making regarding the use of resources in targeting asthma rates is therefore warranted. Effective resource allocation in the control of asthma would be especially beneficial for lower socioeconomic groups.

In this thesis, I build a theoretical model and empirically investigate the link between home heating and asthma hospital admissions in New Zealand. First, I use individual-level survey data from the New Zealand

General Social Survey (NZGSS) to investigate the link between housing conditions and health complications, holding constant available (observable) socio-economic factors. I find evidence of a positive relationship between housing problems such as dampness and cold and general health complications. This provides suggestive evidence that housing may be an important factor in explaining the variance of health states. However, more evidence is needed as to the effects of housing conditions on asthma as the cross-sectional approach is susceptible to endogeneity biases and the NZGSS data does not address asthma directly.

In light of the limitations of the NZGSS analysis, I turn to other data sources and estimation techniques in an effort to control for endogeneity. In particular, I investigate the viability of quarterly regional electricity prices as a proxy for the existence and the type of home heating. I find that electricity prices are good predictors of home heating which allows me to test the hypothesis that higher electricity prices (via less adequate heating) increase asthma admissions. To do this, I first undertake a two-stage least-squares approach, using electricity prices as an instrument for home heating. Results are suggestive of a negative relationship between home heating and asthma admissions. This approach, however, is unreliable due to very limited data and a somewhat imprecise measure of one of the main variables of interest, home heating.

Due to the drawbacks of the two-stage least-squares approach, I focus on reduced-form, panel data estimation as the best available approach to establishing the effect of home heating on asthma admissions. My results provide strong evidence of a positive relationship between electricity prices and asthma admissions. This finding withstands a series of robustness checks including different estimation procedures, changes to the definition of the dependent variable, inclusion of additional explanatory variables, and a straw-man analysis.

The remainder of this thesis is organised as follows: Section two describes the relevant background literature, section three explores the theoretical framework that the following analyses build on, sections four to six discuss the data, methods and results of the cross-sectional analysis of NZGSS (in section four), the Instrumental Variable approach (in section five) and the reduced-form approach (in section six) and section seven concludes.

2. Literature Review

Asthma is a severe problem for many New Zealanders. One in six adults and one in four children in New Zealand suffer from asthma symptoms. New Zealand has one of the highest asthma rates in the world along with other western countries like the USA and Australia (Holt & Beasley, 2002).

Infants and children are particularly susceptible to asthma and it is the leading cause of hospital admissions of children (The Asthma and Respiratory Foundation of NZ (Inc.), 2006). Although asthma prevalence is the highest in wealthy countries, within countries, asthma is manifestly a disease of lower socio-economic groups. In New Zealand, asthma disproportionately affects Maori and Pacific-Islanders in both prevalence and severity (Holt & Beasley, 2002).

Approximately 130 deaths a year are caused by asthma attacks in New Zealand. The direct medical costs to the country of treating asthma have been estimated to be $125million, where a more comprehensive measure of costs including indirect costs to the country such as lost productivity and years lost to disability brings that figure up to $700million (Holt & Beasley, 2002). Given this unsatisfactory state, any information that can help guide effective asthma prevention is of high importance. My research will provide evidence as to the effectiveness of improving house heating as a way of combating asthma.

The main avenue for home heating to influence asthma prevalence and severity is through the effect it has on house dust mites (HDM) survival. HDM require a relatively cool and humid environment to survive (Crane et al, 1998). New Zealand's cold, humid climate provides an ideal atmosphere for the proliferation of HDM throughout households. Adequate home heating can prevent HDM from inhabiting households by reducing humidity below the level critical for the survival of HDM. Other avenues for home heating to affect asthma are through the effect on indoor temperature and through the effect on mould growth.

Randomised housing improvement studies have attempted to assess the causal effect of home heating on asthma rates. The Watcombe housing study conducted in the United Kingdom (Barton et al, 2007) investigated self-reported asthma rates in households with improved heating and insulation and found a significant but negligible effect on asthma prevalence. Two randomized controlled studies in New Zealand (Howden-Chapman et al, 2007, 2008) looked at the effects of housing improvement on asthma and like the Watcombe study found significant but negligible effects on asthma. Crane et al (1998) looked at the effect of installing a Mechanical Ventilation Heat Exchange system on the presence of dust mites in New Zealand homes and found no significant effects. All of these controlled randomized studies plus other similar ones have a few systematic drawbacks: due to the substantial costs of the studies, the time period is often short and the sample size small; asthma is mainly measured by self-reports of symptoms; survey participants cannot be 'blinded' to the intervention ('treatment') which is especially problematic when relying on self-reports; and there are problems with participant compliance. Although some of the studies try to address some of these issues (e.g., the Watcombe study included a nurse assessment of asthma symptoms to complement a portion of the self-reports) the evidence they provide supporting the causal link between home heating and asthma is underwhelming and there is a need for further investigation.

Other studies have evaluated the correlation between asthma and home heating using cross-sectional econometric methods and some have found a negative correlation (Butler, Williams, Tukuitonga, & Paterson, 2003); (Borooah, 2007). However, these studies do not adequately control for wealth, an inherent problem with using cross-sectional data for this type of analysis. The problem stems from the fact that home heating is an endogenous determinant of asthma prevalence due to it being highly correlated with wealth (and possibly other observable and unobservable household characteristics) which can in turn affect asthma prevalence through many potential mechanisms besides home heating. Plausible connections between wealth and health found in the asthma literature include: education, childhood fruit intake, smoking, living in polluted areas, and underlying racial tendencies.

Education is possibly the most important factor contributing to low asthma severity amongst higher socio-economic groups. Michael Grossman's classic paper (Grossman, 1972) explains that education is highly correlated with better health outcomes because people with higher education are not only more likely to have healthy lifestyles, but can also use health inputs more effectively. The nature of asthma is such that it cannot be cured or successfully prevented (at least with current medical knowledge) but it can be effectively managed through the use of inhalers. For the best management of asthma, it is vital that the patient understands how and when to use the inhalers and when they need further assessment from a general practitioner (this may also be further exacerbated by low-income families avoiding general practitioner visits due to cost). Previous literature indicates that the role of education is important in explaining the difference between the severity of asthma amongst low-income and high-income households (Borooah, 2007).

Propper & Rigg (2006) found that low childhood fruit intake was correlated with high asthma rates; it is very plausible that childhood fruit intake is higher among wealthy families. Smoking along with inhaling second hand smoke has been suggested to have a causal relationship with asthma rates (Propper & Rigg, 2006) and, in New Zealand, smoking rates are the highest amongst low-income families. Highly polluted areas can trigger asthma due to the higher particulate matter in the air; it is plausible that low-income families live in areas with more pollution.

Underlying racial tendencies may play an important role in the relationship as well, particularly in New Zealand. Maori and Pacific-Islanders are disproportionately represented in asthma prevalence and severity statistics. For example, Maori are four times more likely to die from asthma than non-Maori (The Asthma and Respiratory Foundation of NZ (Inc.), 2009). It is unclear how much of this relationship is due to the fact that both Maori and Pacific Islanders are also disproportionately represented in lower socio-economic groups; however, there does seem to be a disparity that cannot be explained by observable differences in socio-economic factors.

My research addresses the endogeneity of home heating in a way that has not been attempted in the literature: by using electricity prices as an instrument (or a proxy) for home heating. This will provide a rigorous analysis of the direct effect that home heating has on asthma without the influence of income or other unobserved factors related to both home heating and asthma.

3. Theoretical Framework

The main goal of this research is to investigate how much of an effect home heating has on asthma rates. As discussed above, evidence that suggests there is or at least should be a relationship is plentiful. Hence, a naïve form of my model is as follows:

$$Health\ Complications\ =\ f(home\ conditions)$$

Or, more specifically:

$$Asthma \ = \ f(home\ heating)$$

However, this simplistic model does not account for the problem of endogeneity; both asthma and home heating are correlated with income and other factors – including unobservable ones. This can be illustrated as follows:

$$Asthma \ = \ f(income, home\ heating),$$

$$Home\ Heating \ = f(income)$$

Although, in theory, observable factors such as household income could be measured and controlled for in the above model, accurately accounting for all endogenous factors would be practically impossible and their omission would lead to a biased estimate of the effect of home heating on asthma rates. To account for this endogeneity, my research will introduce an instrumental or proxy variable that is uncorrelated with income (and most of the other plausible endogenous factors) but highly correlated with home heating: electricity price. High electricity prices will reduce electricity consumption (an ordinary good). The amount of energy used for electric heating (space heating – not including heating for cooking water heating etc.) in New Zealand households is the third largest component of total electricity usage at approximately 19% behind water heating (approximately 39%) and Electronics (approximately 20%)

(calculated using the EECA energy end use database (EECA, 2010)). As home heating is a relatively large component of the total electricity usage in New Zealand it is likely that the amount of home heating used will be highly elastic with respect to the price of electricity. Since electricity prices are not correlated with income and other household characteristics, the effect they have on asthma rates will solely be through the effect on home heating. The main form of my model can be expressed as:

$$Home\ heating\ =\ f(\ electricity\ price)$$

$$\rightarrow\ Asthma\ =\ f(\ electricity\ price)$$

A concern with the above reduced-form model is that higher electricity prices may cause people to substitute towards non-electric sources of heating such as gas heaters and wood burners. While this has a potential to counteract the direct effect electricity prices would have on asthma through reduced electric heating as homes may still be heated to a comparable level, the heating appliances themselves may affect asthma. Gas heating - especially unflued varieties - can increase particulate matter in the air of homes and can also increase moisture leading to mould growth plus a higher humidity which helps HDM proliferation (Ministry of Health, 2005). Wood burners may also increase particulate matter in the homes but will also increase particulate matter in the atmosphere outside, worsening the asthma of people in the surrounding area as well as those inside the house. Since the use of alternative fuels such as wood and gas will be influenced by their respective prices relative to electricity prices, we can express the relationships as follows:

$$Use\ of\ altenative\ fuels = f(\ electricity\ price, alternative\ fuels\ price)$$

$$Particulate\ matter = f(use\ of\ alternative\ fuels)$$

$$Asthma = f(\ electricity\ price, alternative\ fuels\ price)$$

In any case, however, the hypothesized relationship between electricity prices and asthma rates is positive – via reduced heating and/or switching to less healthy sources.

4. New Zealand General Social Survey

Using data from the NZGSS, I am able to conduct analyses of the relationship between housing conditions and health complications, holding constant the effect of a range of socio-economic indicators that could otherwise be confounding. As addressed above, this type of cross-sectional approach to analysing the effect of housing conditions on health outcomes, even when controlling for some obvious third factors, does not come without its shortcomings. However, it is a useful exercise in order to explore the correlation that may be able to insinuate causation even if it cannot be entirely conclusive.

4.1. Data

The NZGSS provides cross-sectional individual-level data on a range of socio-economic factors including age, sex, ethnicity, income, education, employment status, smoking status, housing conditions, health outcomes, and deprivation for 8,721 individuals within New Zealand in 2008 With regards to housing conditions, NZGSS includes questions asking survey respondents whether they have major problems with their house in that it is too damp, too cold and/or has too much pollution; whether they have heating in all main rooms of the house; and how many extra bedrooms are 'needed' (if any) for the number of people living in the house (see Table 1. for specific wording). NZGSS deprivation data is based on the New Zealand Index of Deprivation calculated from the 2006 Census (Salmond, Crampton, & Atkinson, 2007). Data on health outcomes is obtained through self-assessed questions about general health and how often health limits the respondent's ability to undertake moderate activities and/or specific activities like climbing the stairs. The respondent's age and income are reported in intervals of five years and five thousand dollars, respectively. The education of the respondent is reported as their highest qualification obtained. Respondents are asked whether they are a current smoker and, if not, whether they had ever been a regular smoker. Ethnic groups available are: Asian, European, Maori, Pacific Peoples and other. These groups are not mutually exclusive and many respondents answered that they belonged to more than one of the groups.

After removing respondents who had refused to answer or did not know the answer to relevant questions, the dataset contained responses from 8,687 individuals. Of these respondents, 865 (10.0%) answered that being too damp was a major problem with their house, 1,459 (16.8%) answered that being too cold was a major problem with their house, and 1,575 (18.1%) answered that they did not have heating available in all main rooms of their house. A comparison with self-reported health measures (Table 2.) shows that people with damp houses, cold houses and without heating in all main rooms feel worse about their general health. However, this does not take into account other factors (such as socio-economic conditions) which may be confounding the results.

4.2. Methods

To examine the role of housing conditions on health outcomes independent of observable socio-economic factors, I use ordinal logit regressions with the following specification:

$$
\begin{aligned}
&Health\ Complications_i \\
&\quad = \beta_0 + \beta_1 Damp_i + \beta_2 Cold_i + \beta_3 Heating_i \\
&\quad + \beta_4 Deprivation_i + \beta_5 Pollution_i \\
&\quad + \beta_6 No\ Qualification_i + \beta_7 High\ School_i \\
&\quad + \beta_8 Employed_i + \beta_9 Low\ Income_i + \beta_{10} Age\ Group_i \\
&\quad + \beta_{11} Maori_i + \beta_{12} European_i + \beta_{13} Pacific_i \\
&\quad + \beta_{14} Current\ Smoker_i + \beta_{15} Never\ Smoked_i \\
&\quad + \beta_{16} Household\ Crowding_i + \varepsilon_i
\end{aligned}
$$

Where i indexes the survey respondent, Damp is a dummy variable equal to one if the respondent indicated that being ‘too damp’ was a major problem with his/her house, Cold is a dummy variable equal to one if the respondent indicated that being ‘too cold’ was a major problem with his/her house, Heating is a dummy variable equal to one if the respondent does have heating in all main rooms of the house, Deprivation represents the (ZIP-code level) value on the New Zealand Deprivation Index that corresponds to the respondent, Pollution is a dummy variable equal to one if the respondent indicated that air pollution was a major problem with their street/neighbourhood, No Qualification is a dummy variable equal to one if the respondent did not finish high school, High School represents a dummy variable with the value one if the respondent’s highest qualification was high school completion or other comparable qualification, Employed is a dummy variable indicating whether the respondent is currently employed, Low Income is a dummy variable equal to one if the respondent had a personal income less than NZD 20,000/year, Age Group represents the age group of the respondent, Maori, European, and Pacific are dummy variables indicating belonging to different ethnic groups, Current Smoker and Never Smoked are dummy variables indicating the respondent's smoking status, and Household Crowding represents a variable for the number of bedrooms needed in the respondent's house (where: 1-two or more needed, 2-one needed, 3-none needed, 4-one spare, 5-two or more spare).

Health Complications is a measure of general health based on the respondent's self-reports (1-excellent, 2-very good, 3-good, 4-fair, 5-poor), or a dummy variable indicating that the respondent is limited in his/her ability to do moderate activities or climb the stairs due to his/her health (see Table 1. for more information on the definitions of the variables).

To assess the magnitude of the effects of the independent variables on the health outcomes, I calculate the marginal effects of a discrete change in the independent variables at their respective mean values for each regression using the Stata command 'mfx compute, dy/dx at(mean)'. For the ordered logit regression, where general health is the dependent variable, I calculate the marginal effect of the propensity to report 'excellent health'.

4.3 Results

Table 3. reports the results from the regression with all variables included. By using a general-to-specific approach when analysing health complications as the dependent variable, I am able to eliminate High School, Household Crowding, European, and Pacific as explanatory variables. The omission of these variables makes for a 'cleaner' resulting model with nothing substantial lost. The variable for no qualification controls adequately for educational attainment, the variable for Maori controls for important ethnicity-related variation, and household conditions are adequately controlled for without the 'household crowding' variable. The resulting regression suggests that all remaining socio-economic factors have the expected effect on general health: higher deprivation, low income, having no qualifications, being Maori, living in a polluted area, and smoking all result in worse general health reported. Being employed and never having been a smoker are associated with better general health. As expected, being in an older age group results in significantly worse reported health.

Most importantly for our purposes, even when holding all the above socio-economic factors constant, there still exists a significant detrimental relationship between poor housing conditions and health. Having heating available in all main rooms improves reported health (but is of lower statistical significance than other factors). Household dampness and cold are both highly significantly related to worse reported health.

Repeating the final regression equation with the dependent variable being whether the respondent was limited in his/her ability to do moderate activities and climb the stairs tells the same story (Table 3). All variables except Maori have the same coefficient signs as in the previous regression, albeit some have lost their statistical significance. Household dampness and cold are both still highly significantly related to worse health outcomes.

An examination of the marginal effects of housing conditions on the propensity of people to report better health outcomes (Table 4.) indicates a relatively large effect of housing conditions on health outcomes. Reporting that dampness is a major problem with the house decreases the likelihood of reporting excellent health by about 5%, not being limited by health to perform moderate activities by about 4%, and not being limited by health to climb the stairs by about 4%. Reporting that a major problem with the house is that it is too cold decreases the likelihood of reporting excellent health by about 4%, not being limited by health to do moderate activites by about 3% and not being limited by health to climb stairs by about 4%. Having heating in all main rooms of the house does not have significant marginal effects on the propensity to report better health outcomes.

From these results (but keeping the limitations of cross-sectional analyses in mind), I can conclude that household dampness and cold seem to worsen health outcomes. Although these conditions likely affect more health problems than just asthma, asthma is likely to be an important contributor to these findings. Hence, there appears to be some evidence from the NZGSS to suggest that home heating can reduce asthma prevalence and/or severity. However, it is plausible that unobservable factors correlated with both housing conditions and health outcomes may be at least partially confounding these results. A different approach with more power to isolate causality is needed.

5. Instrumental Variables/Two Stage Least Squares

An instrumental variable (IV)/two-stage least squares (TSLS) approach is normally considered the preferred way of addressing endogeneity issues (because it produces estimates of the main relationship of interest), hence I attempt an IV model to estimate the relationship between home heating and asthma admissions.

5.1. Data

My data for this section comes from four sources: asthma hospital admissions data from the Ministry of Health, electricity price data from the Ministry of Economic Development, population statistics from

Statistics New Zealand and home heating data from the Census (obtained via Statistics New Zealand). The unit of analysis is a District Health Board (DHB) region[1].

The raw asthma admissions data contains monthly numbers of hospital admissions where the primary diagnosis was identified as asthma separated by five-year age brackets, sex, and three race categories (Maori, Pacific Islander, Other) from July 2000 to June 2009, for each DHB. Unfortunately, for the Instrumental Variable regressions, I can only use annual data from the two Census years in my study period: 2001 and 2006. This is a major limitation of the TSLS approach as only 34 DHB-level data points are available in total. In section six, I use the full, much richer panel dataset to estimate the reduced form effect of electricity prices on asthma admissions.

Although my results are based on asthma hospital admissions rather than asthma prevalence in general, it seems reasonable to assume the results can be generalised to give an indication of the overall asthma burden. The main reason for using hospital admissions as the measure of asthma prevalence is the availability of data, but another major benefit is that the figures are (relatively) objective as they have been assessed by a health care professional. Self-reported measures of asthma prevalence may be

[1] Since 2001, New Zealand has been administratively divided into 21 DHBs.

more thorough but would suffer from the inaccuracy associated with self-assessment of health outcomes.

Since the literature suggests that infants and young children are the most affected by asthma and that once adulthood is reached, age has little effect on asthma (The Asthma and Respiratory Foundation of NZ (Inc.), 2006), I create a sub-sample from the data to analyse the effect on infants (0-4 years) separately. I ignore gender sub-categories as I could not find any suggestion in the literature that there should be any a-priori differences between the two sexes in asthma prevalence.

My descriptive findings based on the full dataset from years 2000-2009 (Figure 1.) are consistent with the literature in showing that asthma is the highest amongst infants and children. In particular, there is a distinctive trend of asthma admissions decreasing until adulthood is reached and changing very little from then on (the drop after 50 years is most likely explained by fewer people above that age rather than lower asthma in that group). As previously documented, Maori are disproportionately represented in asthma admission statistics (Figure 2.) Maori only represent 15% of New Zealand population but 34% of asthma admissions. Finally, initial observations indicate that asthma admissions may have been decreasing over the time period of the sample (Figure 3.); this is at odds with previous studies which suggest asthma incidence has been increasing in recent times (Holt & Beasley, 2002). Table 5. reports descriptive statistics of my ‘admissions’ and ‘infant admissions’ variables (again, based on the full dataset from years 2000-2009).

Electricity price data was obtained from the Ministry of Economic Development’s Quarterly Survey of Domestic Electricity Prices (QSDEP) (Ministry of Economic Development, 2010b). This survey provides quarterly retail electricity price data for each retailer purchasing from a line business from April 1998 to November 2009. The line businesses each service a unique geographical area in New Zealand.

The QSDEP dataset assigns line businesses to regions. However, these regions do not precisely coincide with DHB regions so I have re-assigned line businesses into regions that fit with the DHBs (Table 6.) Most DHB regions are matched very closely to one or more line businesses but there are a couple that do not fit perfectly. This is especially evident on the Lakes/Waikato border and the Southland/West Coast border. However, this should not be a cause of concern because the area of difference is very sparsely populated and given that the electricity price data is only an estimate, the loss in accuracy due to a different border definition will be trivial.

The QSDEP dataset also identifies for each line business region which retailer is the incumbent retailer. Following advice from a representative from the Ministry of Economic Development, I have used the retail prices from the incumbent retailers as my primary measure of electricity prices for a line business. Where there are multiple line-businesses within a DHB region, I have calculated a weighted average of the electricity price within each DHB region weighted by the number of Installation Control Points (ICP) each line business has. For the IV regressions, I take a weighted average of the electricity price within each DHB region over the four quarters of the year to produce an electricity price estimate for 2001 and 2006 for each region. I use the full, rich QSDEP dataset in the following reduced form analysis (section six).

The New Zealand electricity market relies largely on hydro power with 57% of electricity being generated at hydro power plants, on average. The next largest source of electricity is gas at 20% followed by geothermal energy at 11% and coal at 7% (Ministry of Economic Development, 2010a). Due to the high proportion of energy coming from hydro sources, the electricity market is heavily influenced by rain fall at the few relatively compact lake/river regions where the majority of hydro power is generated. Over 80% is generated within four regions that are mostly sparsely populated: the Clutha lakes (about 14%)[2], Lake Manapouri (about 13%)[3], The Waikato River (about 21%)[4] and the

[2] For more information see http://www.contactenergy.co.nz/web/pdf/environmental/Hydro_brochure.pdf
[3] For more information see http://www.meridianenergy.co.nz/NR/rdonlyres/B496C006-3F64-4F0E-8305-C22CAE732A4E/24507/0102MEDManapouriwebBro2.pdf
[4] For more information see http://www.mightyriverpower.co.nz/Generation/PowerStations/HydroStations/Default.aspx

Waitaki Lakes region (about 33%)[5]. Also, the majority of hydro generation takes place in the South Island (where the Clutha lakes, Lake Manapouri and Waitaki Lakes lie) and is transmitted to the much more populated North Island (representing about 64% of electricity demand) through a high voltage direct current (HVDC) link between the two Islands. If the electricity market is highly supply-driven as evidenced by the sustained high electricity prices caused by relatively dry South Island winters in 2001, 2003 and 2006 (Hogan & Meade, 2007), the electricity price is likely to be strongly affected by weather conditions at the source of power generation (affecting supply) but not necessarily by the weather at the end-user's residence (affecting demand) which may be quite different.

The Census (Statistics New Zealand, 2006) conducted in New Zealand every five years provides data on the number of people in each region using different forms of home heating as well as the total number of households. On the dwelling form, respondents are asked to identify any fuels that are ever used to heat the dwelling. The list includes: 'don't ever use any form of heating in this dwelling', 'electricity', 'mains gas (from street)', 'bottled gas', 'wood', 'coal', 'solar heating equipment', and 'other'. This data is reported for DHB regions in the 2001 Census but in the 2006 Census, it is only available for regions that closely, but not

[5] For more information see http://www.meridianenergy.co.nz/NR/rdonlyres/B496C006-3F64-4F0E-8305-C22CAE732A4E/24505/0104MEDWaitakiwebBro12.pdf

perfectly, resemble DHBs. Hence, I had to combine some DHBs to fit the regions in the 2006 Census, reducing the number of available observations to fourteen.

Ideally, I would use a continuous measure of the quantity of home heating people use. The closest measure available in the Census is the number of dwellings in each region using different sources of heating. I therefore focus on the absolute number of households using electric heating and also calculate the proportion of households using electric heating in their house.

Age-specific population data (annual, DHB-level) has been obtained from Statistics New Zealand and includes population estimates stratified into five-year age brackets. I have pooled the age brackets the same way as with the asthma data and have matched the two data sets. I use the population estimates in a weighted TSLS model in order to obtain nationally-representative results.

5.2.Methods

For an initial check to ascertain whether electricity prices are an appropriate proxy/instrumental variable for home heating, I regress the proportion of households using electric heating on electricity prices. Since home heating estimates are annual, I use an average of electricity prices over the four quarters of 2001 and 2006 as the measure of electricity price. In particular, I estimate the following model:

$$Proportion\ of\ households\ using\ electric\ heating_j$$
$$= \beta_0 + \beta_1 electricity\ price_j + \varepsilon_j$$

where j indexes DHB regions and the model is estimated for years 2001 and 2006 separately. I also look at the absolute number of households using electric heating as a function of electricity price and the number of households for both sample years:

$$Number\ of\ households\ using\ electric\ heating_j$$
$$= \beta_0 + \beta_1 electricity\ price_j$$
$$+ \beta_2 number\ of\ households_j + \varepsilon_j$$

Next, using electricity prices as an instrument for the number of dwellings with electric heating, I run an Instrumental Variable regression on asthma admissions using the 'ivregress 2sls' command in Stata:

$$Asthma\ admissions_j =$$
$$\beta_0 + \beta_1 number\ of\ households\ with\ electric\ heating_j +$$
$$\beta_2 population_j + u_j$$

$$number\ of\ households\ with\ electric\ heating_j =$$
$$\gamma_0 + \gamma_1 electricity\ price_j + \gamma_2 population_j + v_j$$

where j indexes DHB regions. The electric heating variable denotes the absolute number of households who use an electric source of heating in a particular region. The population variable represents the number of people in the region in thousands. Since the number of households with electric heating is the variable of interest, it would be ideal if we could control for the number of households in a region as well as regional population. However, including both of these variables is not feasible due to high multicollinearity. In light of this, I run regressions where a variable denoting the number of households replaces the population variable. I repeat the regressions with infant admissions as the dependent variable as well and infant population instead of total population where applicable. All regressions are estimated using the white diagonal standard error adjustment (robust command in Stata). All regressions also contain analytic weights by whatever measure of population is utilised in the regression (i.e., total population, number of households or infant population).

5.3.Results

As expected, electricity price appears to be significantly negatively correlated with households' use of electric heating for both sample years (Table 7.) In particular, in 2001, electricity price has a coefficient of -0.061 (significant at the 99% confidence level), indicating that when electricity price increases by one cent per kilowatt, the proportion of households using electric heating decreases by 6.1 percentage points. Looking at absolute values appears to tell a similar story with higher electricity prices leading to fewer households using electric heating, albeit with very different magnitudes across the two years (likely due to the very small numbers of observations in each regression). The 2006 regresssion for the proportion of houses using electric heating shows no significant relationship. Even though there is some inconsistency in the above results, it seems safe to assume from the estimates (and from economic theory) that households do respond to electricity prices when consuming electric power for home heating. This, combined with the fact that electricity prices do not affect asthma in any way other than through heating use, indicates that electricity prices are a good proxy/instrument for home heating.

Results of the IV regressions are highly volatile (Table 8.) All regressions for the 2001 sample show the number of households with electric heating to be insignificant, regardless of whether all admissions or infant admissions are the dependent variable or whether the number of households or population is used as an additional explanatory variable. In 2006, when the number of households in a region is controlled for, the variable of interest - the number of households with electric heating - becomes highly significant and has the expected sign indicating that higher use of electric heating reduces asthma admissions. Similarly to the NZGSS analysis, the IV approach provides somewhat suggestive evidence that home heating has a causal effect on health complications, specifically, asthma admissions. However, the data limitations are severe and limit the scope of analysis.

6. Reduced Form Approach

Although a reduced form model is not the most direct way of addressing endogeneity issues, given the data constraints of the IV approach, reduced form estimation offers significant advantages. By not having to include the variable for household heating, the number of usable data points increases from a maximum of 20 to a maximum of 720 in any one regression. This fact renders the reduced form a much more methodologically sound approach. In addition, the increased sample size allows for a wide range of robustness checks to be performed, further solidifying this approach as the superior one for this situation.

6.1 Data

In addition to the asthma admissions, electricity price, and population data used in the IV approach, the reduced form approach also uses data from the following sources: cerebro-vascular disease hospital admissions from the Ministry of Health, gas prices from the Ministry of Economic Development, Consumer Price Index (CPI) values from Statistics New Zealand, and smoking rates and deprivation indices from the Census.

For my regression analysis, I use quarterly data by DHB regions for the period between the third quarter of 2000 to the second quarter of 2009. The quarters are defined as follows: first quarter (Q1) January-March, second quarter (Q2) April-June, third quarter (Q3) July-September, and fourth quarter (Q4) October-December. The second and third quarters, combined, represent New Zealand Winter and the colder months of spring and autumn; the first and fourth quarters, combined, represent New Zealand Summer and the warmer months of spring and autumn.

I have stratified the data by age into three distinct categories: infants (0-4 years), children (5-14 years), and adults (15+ years). The above age brackets were selected for two reasons: 1. the literature suggests that infants and young children are the most affected by asthma and that once adulthood is reached, age has little effect on asthma (The Asthma and Respiratory Foundation of NZ (Inc.), 2006) and 2. using five-year age brackets would be problematic as there would be a large number of zero observations. As previously, I ignore gender sub-categories.

To conduct a "straw-man" analysis (explained in detail below), I have obtained data on cerebrovascular disease admissions, of which stroke admissions are a major component, from the Ministry of Health. This data is stratified by DHB and age brackets. As stroke admissions have a different age distribution to asthma admissions, it seems unnecessary to compare age categories. Therefore, the data is summed to quarters but no stratification by age is performed.

Like in the IV approach, electricity price data comes from QSDEP and, for the purposes of the reduced form analysis, I have created a weighted average price per quarter per DHB region across incumbent retailers. Given an average electricity price of 18.7 and a standard deviation of 3.7 (Table 5.), there appears to be sufficient variation in electricity price for a reliable panel regression analysis. As a robustness check, I also employ a measure of retail electricity prices calculated as a weighted average of the price for each DHB region across all retailers as opposed to just the incumbent retailers. The relative weight of each retailer can be estimated by the number of Installation Control Points (ICPs) each retailer controls. Data on the number of ICPs was obtained from the Electricity Commission website (The Electricity Commission, 2010). This data contains the number of ICPs per retailer for each Network Supply Point (NSP) in New Zealand. As each line business controls several NSPs, I have summed the number of ICPs per NSP data to each line business. I use these for the relative weights of each retailer when constructing a weighted average price for each region and time period. Unfortunately, not all retailers have price data available; in some DHB/quarter cells, only 4% of the market had price data available. This is discussed further below.

Gas price data was obtained from the Ministry of Economic Development. The data set contains monthly data on gas prices for 31 cities and towns in the North Island from 2001. I use the data from cities and towns to represent the DHBs they are in, which provides data for all North Island DHBs except Wairarapa. Unfortunately, there are many missing observations so in total only 178 DHB/quarter cells can be used. No data is available on the number of customers subscribing to each price plan in individual towns and cities, so there is no way to produce an accurate weighted average price. To address this limitation, two measures of gas price were produced: 1. the lowest price in the DHB and 2. an un-weighted average of all pricing plans available in the DHB. Both approaches are problematic but are the best achievable with limited data. In the raw gas price dataset, the Ministry of Economic Development assumes any available discounts were taken advantage of, for example duel fuel and prompt payment discounts. This assumption carries over to my two gas price measures.

Age-specific population data (annual, DHB-level) obtained from Statistics New Zealand for years 2000-2008 is the same as in the IV approach. As this data only goes up to 2008, I have assigned 2008 population estimates to observations from 2009. I have merged the age brackets the same way I have with the asthma data and matched the two data sets. This allows me to express asthma admissions as rates per

10,000 population rather than absolute numbers. The population data is annual whereas all my other datasets are quarterly. This should not be a significant issue as it is unlikely that there is high population variation within a DHB/year. I have also obtained ethnic population data from Statistics New Zealand, which I have grouped into three ethnic categories: Maori, Pacific Islander, and Other. I repeat all of my main models on age and ethnicity subsets.

To produce estimates of inflation-adjusted real prices, I have obtained CPI data from Statistics New Zealand. National, quarterly CPI data is available for the whole period of my sample and has been used to create a real price measure. Regional CPI data only separates New Zealand into the three main cities (Auckland, Wellington and Christchurch) and the rest of the North and South Islands and is only available from the second quarter of 2006. These regional CPI estimates have been assigned to their respective DHBs to produce a slightly more accurate regional real price measure than the national CPI. Since the regional measure limited the number of useable observations, both CPI estimates are utilised in my analysis below.

Data on smoking prevalence by DHB was obtained from the 2006 Census. Smoking information is only asked every second Census (i.e., once in ten years) so there are no other years in my sample that have smoking prevalence data available. Only one observation is available for each

DHB which limits the scope for analysis. The Census asks respondents on the individual form whether they are a regular smoker and, if not, whether they have ever been a regular smoker, producing the following four categories: regular smokers, ex smokers, never smokers, and not stated (with a low non-response rate of 5.2%). From this data, I calculate the percentages of regular smokers and of people who have never been a regular smoker in each region.

To account for economic differences between DHBs, I include data from the NZDep2006 Index of Deprivation - NZDep (Salmond, Crampton, & Atkinson, 2007). The deprivation index is a continuous derived variable measuring deprivation standardised to have a mean of 1,000 and standard deviation of 100. The measure of deprivation is calculated over nine dimensions: income below a certain level, whether the respondent receives a means-tested benefit, home ownership, single-parent family, employment, qualification, household crowding, access to a telephone, and access to a car. Deprivation values are calculated for areas, not individual people. Index values are available for small sized 'census area units' which I have aggregated up to DHB level using a weighted average of the index value (weighting by population). Since this data is based on the Census, it is only available for one yearly observation in 2006.

6.2.Method

First, I regress asthma rates on electricity prices to establish their reduced-form relationship, initially using Ordinary Least Squares (OLS).

$$Asthma\ admissions_{j,t} =$$
$$\beta_0 + \beta_1 electricity\ price_{j,t} + \beta_2 population_{j,t} +$$
$$time\ \&\ cross\ sectional\ fixed\ effects + \varepsilon_{j,t}$$

where j indexes DHB regions and t indexes quarters. As long as the dependent variable is the number of admissions (as opposed to the rate of admissions), it is critical that population be included in the regression, as regions with higher populations are likely to have a higher number of admissions, ceteris paribus. Regional, yearly, and quarterly fixed effects are included to control for time-invariant DHB characteristics and for national time trends and seasonal effects, respectively. I have separated the time periods into years and quarters with fixed effects for each in order to separate seasonal effects from an annual trend. I also weight observations by population to give higher importance to regions where a larger share of the New Zealand population lives and thus to make my results nationally representative. It is likely that some regions will have more variable asthma rates than others. To account for this fact (heteroskedasticity), I have applied the white diagonal adjustment (robust standard errors in Stata) in all my analyses.

The above model specification serves as a baseline. In a series of sensitivity analyses, I adjust the functional form and estimation method, including the following checks: transforming the dependent variable to a proportion (admission rate) rather than an absolute value of admissions; transforming the model to log-linear, log-log and linear-log specifications; adding in a one-quarter lag of the dependent variable as an explanatory variable; and estimating the regressions with Panel-Corrected Standard Errors (PCSE). I repeat this process with the dependent variable stratified by age and ethnicity categories with the corresponding population statistics.

To check that my results are not unduly sensitive to the definition of my main explanatory variable, I repeat my baseline regression with a more comprehensive weighted-average electricity price and with inflation-adjusted electricity prices. As mentioned in the previous section, the weighted-average electricity price measure is problematic due to missing data. To address this problem, I have included two different measures where problematic observations have been omitted. By one measure, I drop the five DHBs with the smallest average percent of the market accounted for (all less than 60%); for my second measure, I drop all DHB/quarter cells with the percentage of the market accounted for less than 45%.

To check whether the effect of electricity price on asthma admissions is due to the ‘quantity’ of home heating or substitution to alternative fuels, I include data on gas prices as an additional explanatory variable. If the ‘substitution effect’ is the more important of the two, we would expect to see the magnitude and significance of the coefficient on electricity price to drop notably, and the coefficient on gas prices to be negative and significant (as gas heating is less beneficial to asthma-sufferers than electric heating).

For a “straw man” robustness check, I check whether the methodology used for asthma gives a significant relationship between home heating and cerebrovascular disease, pointing to a spurious correlation in my asthma findings. Cerebrovascular disease was chosen for the straw-man analysis because it is an acute condition so the time of admission should be a reasonable estimate of the onset of the condition, it is common, and most importantly there is no prominent evidence or theory that it could be correlated with home-heating.

It would seem to be the case that if home heating is driving the correlation between asthma and electricity price, then electricity price should have a larger effect in colder regions and/or quarters. To test for this, I run a series of regressions interacting electricity prices with both quarter and DHB dummies to see if electricity prices have a larger effect in the Winter quarters (Q2 and Q3) and in colder regions (mainly the

South Island). I also repeat the price interaction using binary variables for winter (comprising of Q2 and Q3) and the South Island instead of the full set of quarter and DHB dummies. If home heating is the driving factor behind the relationship between electricity price and asthma, then we would expect the interaction between the Winter dummy (or Q2 and Q3) and price, and the interaction between the South Island dummy and price to be positive indicating that electricity prices matter more (via their effect on heating) in colder areas. I also run a three-way interaction between electricity prices, winter and the South Island dummies to test if electricity price has a larger effect on asthma admissions during winter for the South Island, which would be expected.

In order to analyse what effect smoking behaviour has on asthma rates and whether this affects the main results, I run regressions including variables for the proportion of the population who are regular smokers and the proportion of the population who have never been a regular smoker, separately and together. Since this data is only available for each DHB for one annual observation in 2006, I can only utilise 80 observations in these regressions and can no longer include regional fixed effects due to perfect multicollinearity with the smoking variables. Since the sample size is reduced for these regressions, I compare the results to the baseline regression with the smaller sample (without the smoking variables). Following the baseline regressions, all regressions are weighted by population and standard errors are adjusted using the white diagonal adjustment.

To account for the influence of socio-economic status on asthma admissions and to ascertain whether this affects the main relationship, I run regressions including the deprivation index score for each DHB. Similarly to the smoking data, the deprivation index scores are only available for every other Census year (i.e., once in ten years) and therefore I can only include observations from 2006 reducing the sample to 80. As above, I compare the results to the baseline regression with the limited sample. Deprivation index scores are included as an additional explanatory variable in the baseline model. Once again, I repeat the analysis with infant admissions as the dependent variable.

6.3.Results

As hypothesised, the effect of electricity prices on asthma admissions is positive and highly significant in my baseline specification (Table 9.), indicating that if the price of electricity increases by one cent per kilowatt, holding population constant, the number of hospital admissions for asthma will increase by around seven people, on average, in any quarter in any DHB region. This result withstands most robustness checks for example, adding a lag of the dependent variable does not substantially affect the magnitude or significance of the coefficient on price. Similarly, various log transformations of the dependent and independent variables do not greatly affect the significance of the price (or log (price)) coefficient. When admissions are in log format, the price coefficient is less significant than otherwise but still comes under the 90% threshold. Applying the coefficients to an average region and quarter produces similar magnitudes of effects as the linear model (roughly six additional admissions for every one cent increase). However, converting the dependent variable to the form of rates eliminates the significance of the price coefficient regardless of whether population and the lagged dependent variable are included as explanatory variables. It is plausible that this result is due to the fact that population numbers are annual rather than seasonal and hence produce inaccuracies in the measurement of rates. Also, including population estimates in the denominator of the dependent variable rather than as an explanatory variable makes the specification of the role of population less flexible.

The coefficients on the year dummy variables become increasingly negative for later years (where the first year – 2000 – is the omitted dummy variable), confirming that asthma admissions have been decreasing throughout time. The coefficients on the quarterly dummies indicate that asthma admissions are highest in the first quarter of the year (January to March) and lowest in the third (July to September) indicating that asthma is a bigger problem in the warmer months than the colder ones. Coefficients on the regional dummies suggest that South

Canterbury has consistently the highest asthma admissions and Waitemata and Auckland have the lowest, holding all else constant.

To summarise, the initial specification produces a positive and highly significant coefficient on electricity price, suggesting increasing electricity price by one cent per kilowatt in any quarterly time period will increase asthma hospital admissions (through reduced home heating) by about seven people within a DHB region for that particular quarter. The probability that this relationship was found by chance is less than 0.1%. This relationship is robust to estimation through random effects and PCSE estimation as long as time trends and population are controlled for. It is not robust to the exclusion of time trends but this is as expected since electricity prices have been increasing throughout the time period of my sample whereas asthma admissions have been decreasing. Finally, the above results are not robust to the dependent variable being expressed in rates rather than absolute values (likely due to imprecise/aggregated population estimates) but are reasonably robust to log transformations.

Next, I apply the baseline specification to the separate age and ethnicity categories (Table 10.) The effect of electricity price on asthma admissions is positive and highly significant for infants but not for children or adults. This suggests that the main effect of home heating on asthma is through the effect on infants; which makes intuitive sense firstly because infants are by far the most likely to be admitted to hospital for asthma (comparison of rates) and also because infants probably spend a lot more time at home than any other age group, so would be affected the most by housing conditions. The results for infants are very robust to functional form changes and different estimation techniques, even to expressing the dependent variable as the admission rate as opposed to the absolute number of admissions. The results for children remain insignificant with all functional forms and estimation technique adjustments. This may be because children tend to suffer from asthma attacks at school rather than at home but further analysis is needed before any reliable conclusions can be made from these results. The results for adults tend to produce positive but not quite significant coefficients on price for different functional forms. Since the results are insignificant, it would not be reliable to conclude that there is a positive effect of price on adult admissions but it seems reasonable to assume at least for the time being that this is more likely than not. The results from the ethnicity specific regressions show only the 'other ethnicity' category to have a positive and significant coefficient on price. However, the electricity price coefficient is significant for Pacific Islander infants and of a similar magnitude to the respective coefficient for all infant admissions.

Table 11. presents results from a model using the more comprehensive weighted-average price definition in the baseline regression for both all admissions and infant admissions. Three different sets of included

observations are presented. When all available observations are included, the coefficient on electricity price is still positive and of a similar magnitude as in the baseline regression but is no longer significant for all admissions. Omitting DHBs with the least representative data increases the significance of the electricity price coefficient for both all admissions and infant admissions. The last selection of dropped observations brings the significance and magnitude of the coefficients back to their level when no observations are dropped. While the coefficient on electricity price loses significance for all admissions, it stays strongly significant and of a consistent magnitude for infant admissions. Due to the problematic nature of this definition of electricity price, the original measure is used in all subsequent regressions.

Regressions using inflation-adjusted electricity prices are presented in Table 12. Redefining the electricity price to account for inflation using the national CPI has no considerable effect on the electricity price coefficient’s magnitude or significance for all admissions and infant admissions. Interestingly, adjusting for inflation makes the electricity price coefficient for child admissions significant but has little effect on the coefficient for adult admissions. Using the regional CPI measure comes at a cost of losing 460 observations. It is not surprising that the significance of the regular electricity price decreases but it still stays within the 90% threshold. Adjusting for inflation with the regional CPI measure, again, has little effect on the magnitude or significance of the electricity price coefficient.

The results of models including gas prices as an additional explanatory variable are detailed in Table 13. Unfortunately, due to the limited number of observations in the subsample with available gas price data, the electricity price coefficient is no longer significant. The inclusion of gas prices as an explanatory variable has negligible effect on the size and significance of the electricity price coefficient and is itself not significant. This could be tentatively interpreted as implying that substitution from electric heating to gas heating is not the cause of the relationship between electricity price and asthma admissions. However, since the coefficients are not significant, no reliable conclusions can be made from these results.

Table 14. details the seasonal and regional interactions with the electricity price variable. Although there are fewer asthma admissions in Winter, as indicated by the negative coefficients on Q2 and Q3 variables, the sensitivity of asthma admissions to the price of electricity increases during Winter, as indicated by the positive coefficients on the Price*Q2 and Price*Q3 variables. This is consistent with my hypothesis that poor home heating contributes to increased asthma admissions. Interacting electricity price with a dummy variable for the South Island produces a negative coefficient, which seemingly contradicts my hypothesis that in colder regions asthma admissions should be more sensitive to the

electricity price. However, the fact that most admissions occur during summer may be confounding this result. To address this, I produce a three-way interaction between electricity price, winter, and the South Island. The results from this interaction imply that in the South Island during winter, electricity price has a greater positive effect on asthma admissions than it does in the North Island or during summer. Interacting the South Island dummy variable with the quarter dummy variables confirms that winter has a larger effect on asthma admissions for the South Island than the North Island. Finally, interacting electricity price with DHB regions, I have been able to produce a measure of the elasticity of asthma admissions with respect to electricity price in each region (Figure 4.) Darker regions in Figure 4. represent higher elasticity. Although not overwhelmingly clear, there appears to be a pattern of more Southern regions having higher elasticities. The estimated elasticity would likely be related to the proportion of people who actually use electric heating and would therefore be affected by increasing electricity price. Figure 5. reports these proportions for each DHB region, with darker regions indicating higher proportions.

Results from the straw-man analysis are presented in Table 15. Repeating my baseline regression using cerebrovascular disease admissions instead of asthma admissions produces a highly insignificant coefficient on electricity price. This suggests that the results of my baseline regression are not merely due to spurious correlation and thus supports my main findings above. Not including population weights increases the significance of the electricity price variable but it is still well outside the range of probable correlation.

Repeating the baseline model on the reduced sample with available data on smoking gives the same result of a positive and highly significant coefficient on electricity price. Controlling for the percentage of the population who have never been regular smokers has little effect on the magnitude or significance of the electricity price coefficient (Table 16). The coefficient for those who have never been smokers is negative, as expected, but not significant. Controlling for the proportion of the population who are regular smokers instead again has little effect on the significance of electricity price and although it does reduce the magnitude considerably, the coefficient is still highly positive. In accord with intuition, the coefficient for current smokers is positive and significant. Including both smoking variables simultaneously in the regression tells a similar story: the electricity price coefficient remains highly significant and positive and the percentage of current smokers also significantly increases asthma admissions. The coefficient for the proportion of people who have never been smokers reverses its sign but is still insignificant.

Including the DHB-level deprivation indices has little effect on the coefficient on electricity price (Table 17). The baseline model with the reduced sample for infant admissions retains the highly positive and significant coefficient on electricity price. Including the deprivation index score has no qualitative effect on the electricity price coefficient when considering all admissions. Looking at just infant admissions, statistical significance is reduced considerably but remains above the 95% level. Interestingly, the coefficient on the deprivation score is insignificant. Adding the proportion of smokers further reduces the significance of the deprivation coefficient questioning its explanatory power in a model of asthma admissions.

7. Discussion & Conclusion

An analysis of NZGSS data provides empirical support for the theory that housing conditions including dampness and cold are affecting health outcomes even when socio-economic factors are controlled for. An IV approach further indicates that electricity prices are a good proxy for the type of home heating people use and that home heating specifically affects asthma admission rates.

Results from a reduced form regression imply that asthma admissions are strongly correlated with electricity price. Robustness checks of the functional form indicate that the relationship between asthma admissions and electricity price is more robust for infants than it is for the general population. However, even the general findings remain qualitatively consistent across model specifications. Redefining the electricity price measure to account for a more comprehensive weighted average of retailers supports the above findings. In particular, while the significance of the coefficient on electricity price is affected by the new definition for all admissions, the magnitude and sign are not lost and the coefficient for infant admissions is largely unaffected. The results are strongly robust to adjusting the electricity price for inflation.

Including gas prices as an additional explanatory variable unfortunately cannot contribute much to the analysis due to the low number of observations with available data. Since the magnitude and significance of the coefficient on electricity price are not largely affected by the inclusion of gas prices, it could be tentatively suggested that substitution to alternative fuels that are detrimental/less beneficial to asthma is not the main driver for the correlation between electricity prices and asthma admissions. However, the paucity of the data renders any strong conclusions unreliable.

Estimates of seasonal and regional interactions with electricity price further support the hypothesis that electricity prices affect asthma through their effects on home heating. Although asthma admissions are higher in summer, the effect of electricity prices on asthma admissions is higher in winter. Somewhat surprisingly, electricity price has a smaller effect in the (colder) South Island in general. However, during winter, it has a larger effect in the South Island. Finally, there also appears to be a suggestive regional pattern with the elasticity of asthma admissions with respect to electricity price increasing towards the South. All of these observations are consistent with the hypothesis that increasing electricity prices increase asthma admissions by reducing the level of home heating.

Insignificant results from the straw-man analysis strengthen the baseline findings as they indicate there is no spurious relationship between electricity prices and hospital admissions underlying the significance.

Including smoking indicators as additional explanatory variables has no qualitative effect on the electricity price coefficient, indicating that the relationship is robust to the influence of smoking behaviour. The coefficients on the smoking variables indicate that higher proportions of current regular smokers in a region increase the number of asthma admissions.

Analyses including deprivation scores indicate that the relationship between electricity price and asthma admissions is robust to the inclusion of socio-economic factors. The fact that the deprivation score is highly insignificant could potentially imply that a substantial component of the effect socio-economic factors have on asthma rates is due to differences in home heating. However, more work would have to be done before such a claim could be made with confidence.

Further work is warranted to disentangle the relationship between asthma and indoor heating for school children. My results show no significant relationship but this is likely at least partly due to children spending time at school where the incentive to save on electricity by reducing heating is presumably less direct than at home. School terms, in particular the start of the school year, have a well-documented affect on asthma hospital admissions (Julious, Osman, & Jiwa, 2007). It has been suggested that the increase in social contacts and the associated increase in viral susceptibility is the culprit (Lincoln, Morgan, Sheppeard, Jalaludin, Corbett, & Beard, 2006). It is also plausible that being at school might influence the reported number of asthma attacks and potentially admissions without affecting the underlying prevalence or severity of asthma if schools are more inclined to refer a child for medical intervention than parents who may feel more comfortable handling the symptoms themselves. An interesting area of investigation would be to look at the effect school terms have on asthma admissions outside of other (e.g., weather-related) seasonal variations.

Another contentious issue is that weather may be an uncontrolled factor influencing my results. If particularly cold winters have a significant effect of increasing asthma admissions and also increase the demand for electricity, increasing its price, then the positive relationship between asthma admissions and electricity price that I have found may be merely reflecting the simultaneous effects that weather has on both of these variables. However, due to electricity prices in New Zealand being more supply-driven than demand-driven as discussed in the literature review, it is doubtful that weather would have a large enough impact on electricity price to distort these results. Also, the seasonal, annual and regional fixed effects should control for a large fraction of the deviations in temperature that may affect admissions. That said, controlling for temperature and precipitation would be a worthwhile exercise for future work on this topic.

Another possibility to consider is that insulation or substitution to more efficient forms of heating may be influencing my results. The concern is that high electricity prices would encourage people to invest in more energy efficient forms of heating such as heat pumps and/or better insulation of their homes. Although this is a probable reaction to higher electricity prices, it is more likely to be a decision made over a longer period of time than what this thesis is analysing. It seems unlikely that many people would adjust their heating in the quarter of a price increase. Therefore, it is doubtful that the effect of people improving their insulation or form of heating in the same season would bias my results. Moreover, even if that was the case, it would bias my results downwards. In particular, if people adjust to higher electricity prices by improving the efficiency of their home heating allowing them to have increased heating for the same cost, this should improve asthma symptoms and thus lower the number of asthma admissions, ceteris paribus. This makes my results conservative estimates of the effects of home heating levels on asthma admissions.

Overall, my results strongly suggest that there is a highly significant, positive relationship between the lack of home heating and asthma hospital admissions. This relationship seems independent of other socio-economic factors such as income. Since asthma is such a prominent problem in New Zealand, these findings may have important implications for public health policy.

Figure 1. Number of Hospital Asthma Admissions by Age; New Zealand, July 2000 – June 2009

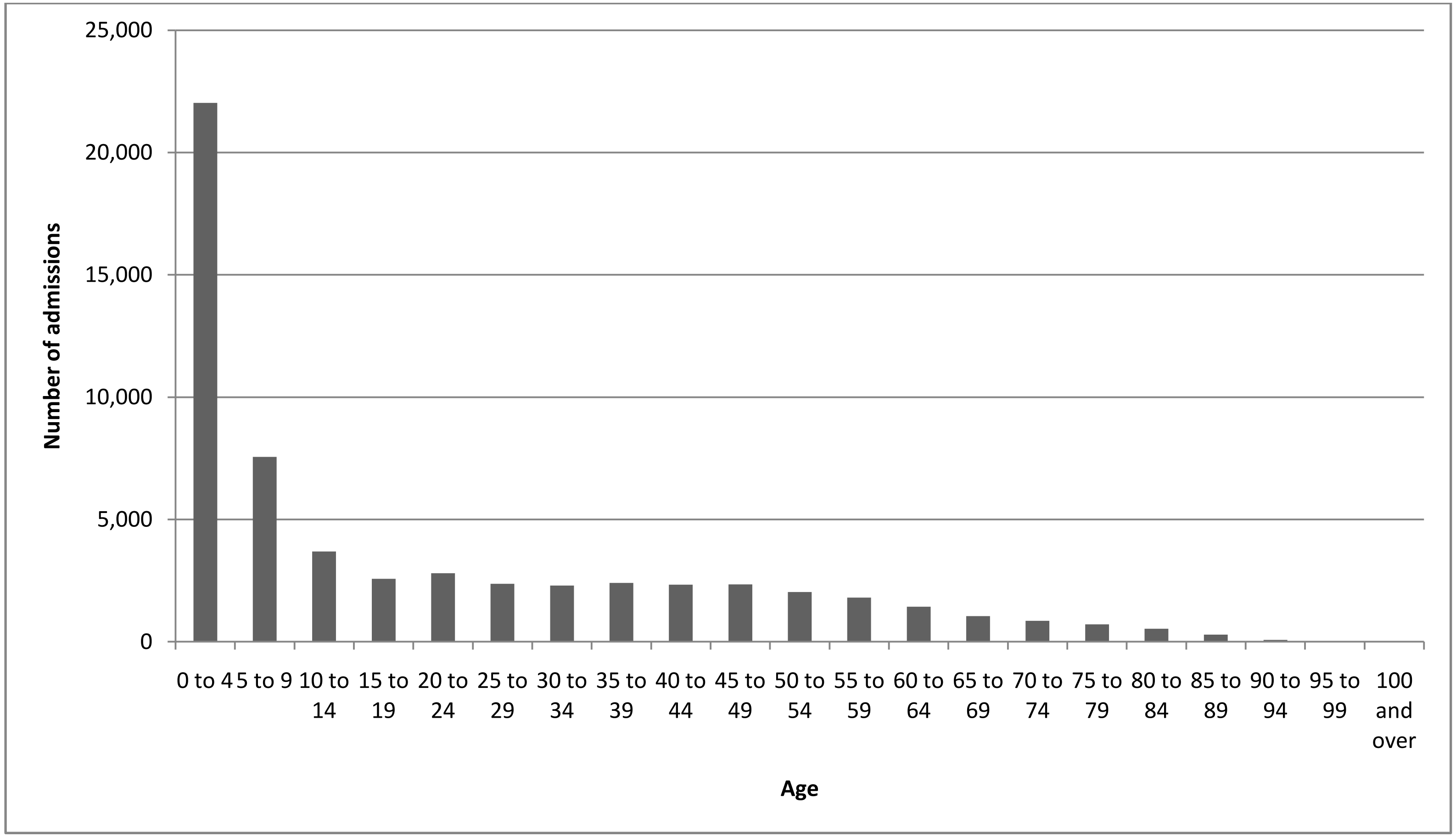


Figure 2. Hospital Asthma Admissions by Ethnicity vs. Population by Ethnicity; New Zealand, July 2000 – June 2009

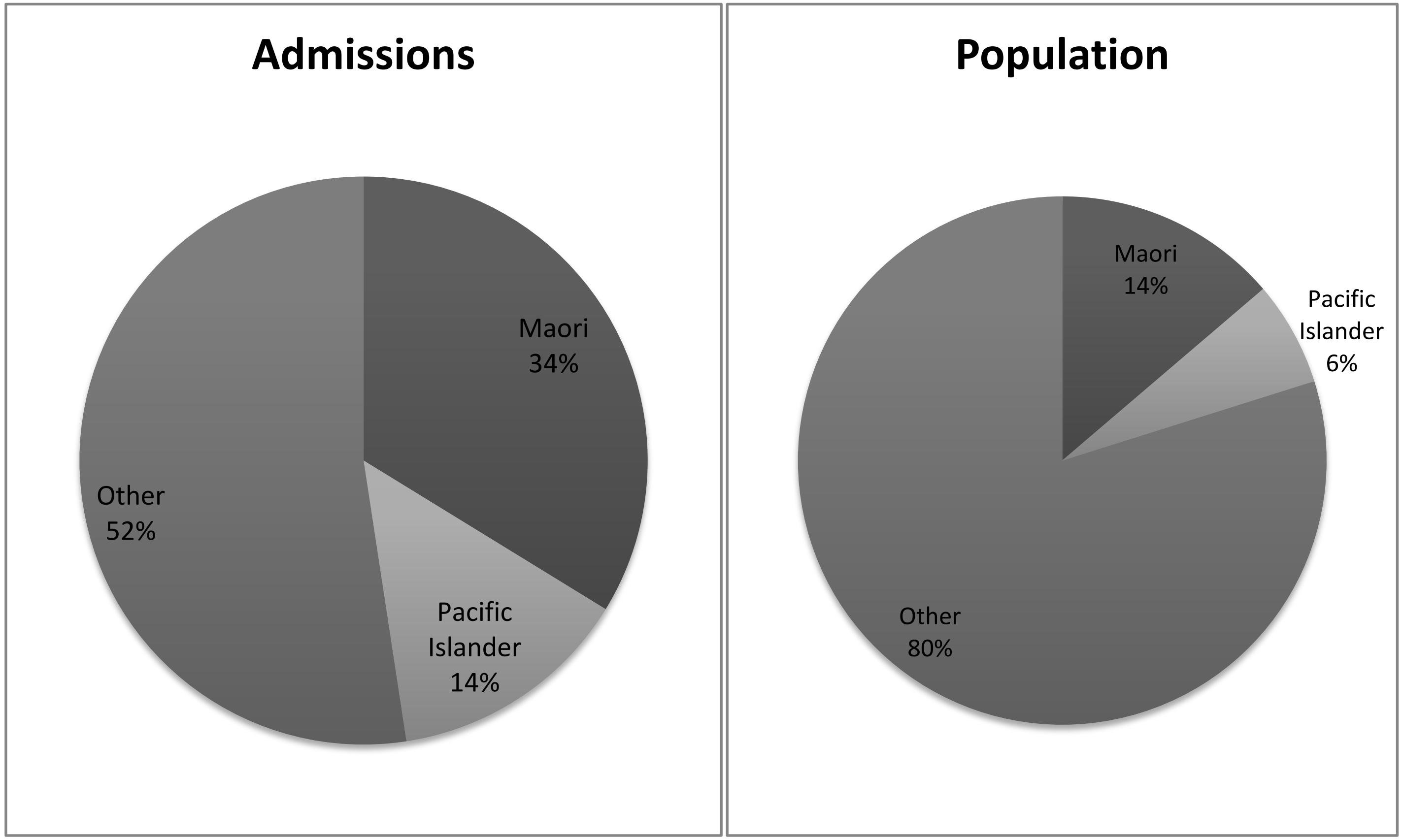


Figure 3. Annual Numbers of Hospital Asthma Admissions; New Zealand; July 2000 – June 2009

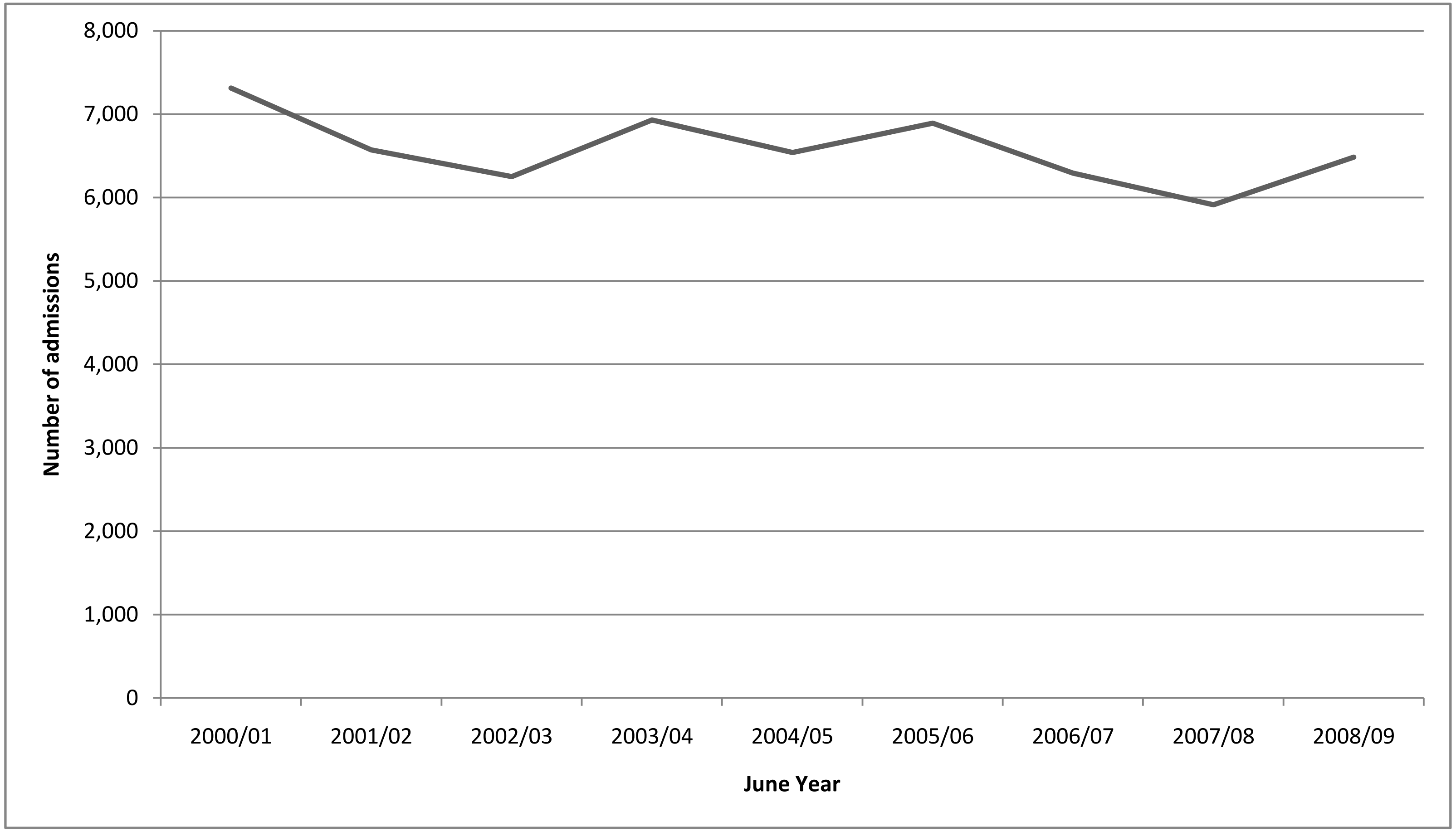
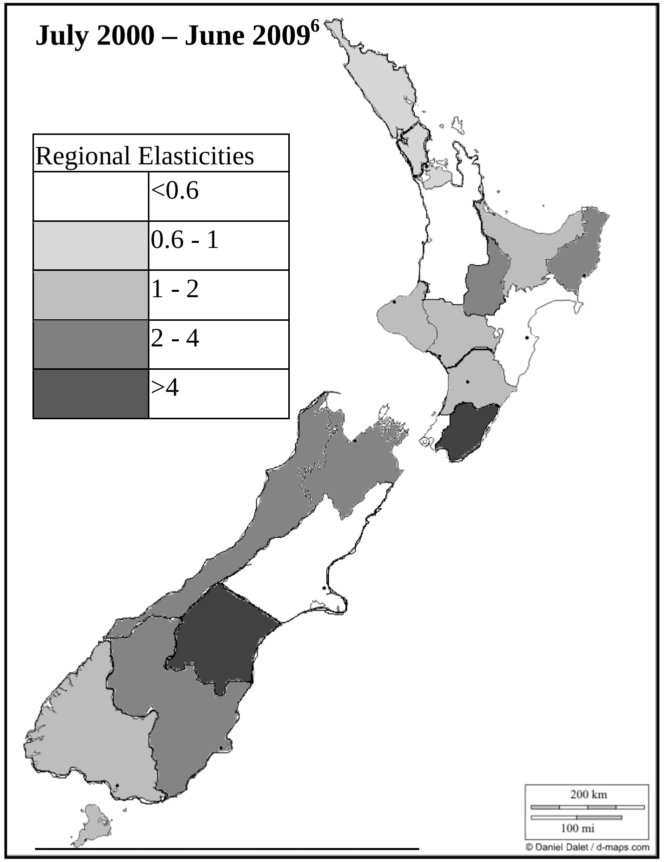


Figure 4. Estimated Regional Electricity Price Elasticities;

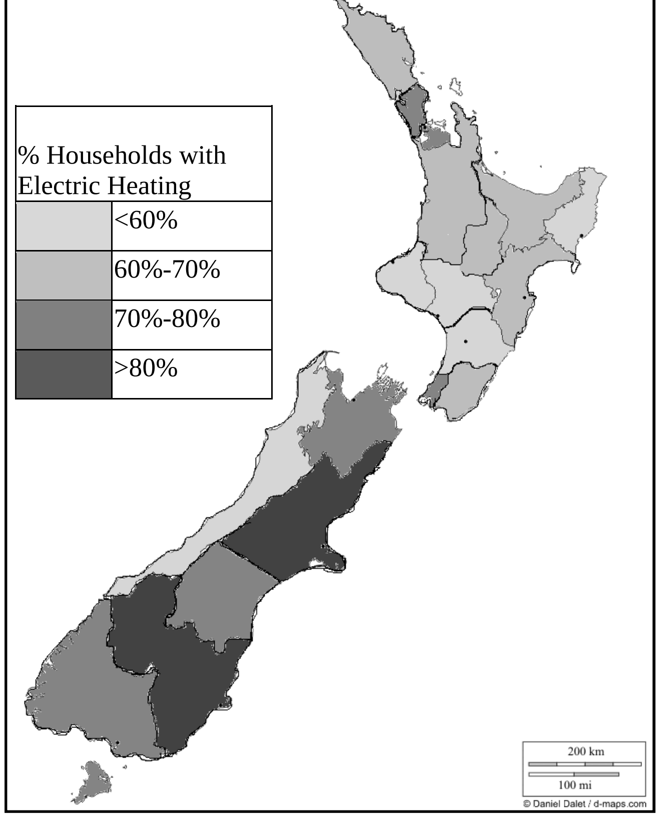
July 2000 – June 2009[6]



[6] Elasticity=change in asthma admissions for a given change in electricity price (coefficient on electricity price + regional dummy coefficient) *(average electricity price/total admissions)

Figure 5. Percentage of Households Using Electric Heating;

2001[7]



[7] Percent of households using electric heating = number of households with electric heating/number of households *100

Table 1. 2008 NZGSS Questions Regarding Health, Housing Conditions, and Pollution

Code	Question	Responses
HEAQ01	In general, would you say your health is excellent, very good, good, fair or poor?	11- excellent 12- very good 13- good 14- fair 15- poor
HEAQ02a	During a typical day, does your health limit you when doing moderate activities such as moving a table, pushing a vacuum cleaner, bowling, or playing golf?	11- yes, limited a lot 12- yes, limited a little 13- no, not limited at all
HEAQ02b	During a typical day, does your health limit you climbing several flights of stairs?	11- yes, limited a lot 12- yes, limited a little 13- no, not limited at all
HEAQ03	During the past four weeks, how much of the time have you accomplished less than you would like as a result of your physical health?	11- all of the time 12- most of the time 13- some of the time 14- a little of the time 15- none of the time
HEAQ04	During the past four weeks, how much of the time were you limited in the kind of work or other regular daily activities you do as a result of your physical health?	11- all of the time 12- most of the time 13- some of the time 14- a little of the time 15- none of the time
HOUQ04_15	Air pollution from traffic fumes, industry or other smoke is a major problem with the person's street/neighbourhood	0. No 1. Yes
HOUQ03_14	Being damp is a major problem with the person's house/flat	0. No 1. Yes
HOUQ03_15	Being too cold, or difficult to heat/keep warm is a major problem with the person's house/flat	0. No 1. Yes

Table 2. Mean General Health Scores[8] by Home Heating Status; NZGSS, 2008

	Heating in all Main Rooms		Dampness is a Major Problem		Cold is a Major Problem	
Response	Yes	No	Yes	No	Yes	No
Mean General Health	2.373	2.475	2.669	2.361	2.59	2.352
Observations	7113	1574	865	7822	1459	7228
Probability of equal means	0.001		0.000		0.000	

[8] Higher numbers indicate more health complications. In particular, NZGSS response options are as follows: 1-excellent, 2-very good, 3-good, 4-fair, 5-poor.

Table 3. 2008 NZGSS Ordered Logit Results[9]

	Health Complications[10]	Health Complications	Limited From Moderate Activities	Limited From Climbing the Stairs
Damp house	0.370*** (0.000)	0.367*** (0.000)	0.301*** (0.004)	0.242** (0.020)
Cold house	0.293*** (0.000)	0.293*** (0.000)	0.326*** (0.000)	0.234*** (0.006)
Heating in all main rooms	-0.094* (0.093)	-0.0938* (0.089)	-0.059 (0.469)	-0.0954 (0.230)
Employed	-0.422*** (0.000)	-0.42*** (0.000)	-0.649*** (0.000)	0.534*** (0.000)
Low income	0.223*** (0.000)	0.226*** (0.000)	0.0378*** (0.000)	0.319*** (0.000)
Pollution	0.266** (0.010)	0.26** (0.012)	0.292** (0.027)	0.253* (0.052)
NZDep	0.049 (0.000)	0.0494*** (0.000)	0.0581*** (0.000)	0.0893*** (0.000)
No qualification	0.286*** (0.000)	0.299*** (0.000)	0.173** (0.010)	0.259*** (0.000)
Age	0.089*** (0.000)	0.0884*** (0.000)	0.211*** (0.000)	0.236*** (0.000)
Maori	0.085 (0.238)	0.133** (0.048)	-0.114 (0.270)	0.084 (0.385)
Never smoked	-0.176*** (0.000)	-0.172*** (0.000)	-0.137** (0.043)	-0.2*** (0.003)
Smoker	0.539*** (0.000)	0.541*** (0.000)	0.128 (0.142)	0.145* (0.084)
European	-0.105 (0.110)	-	-	-
Pacific	-0.111 (0.314)	-	-	-
High School	0.028 (0.545)	-	-	-

[9] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.
[10] Higher numbers indicate more health complications. In particular, NZGSS response options are as follows: 1-excellent, 2-very good, 3-good, 4-fair, 5-poor.

Household Crowding	-0.166 (0.476)	-	-	-
Observations[11]	8,687	8,687	8,687	8,687

[11] All NZGSS respondents excluding only those who refused or didn't know the answer to relevant variables

Table 4. 2008 NZGSS Marginal Effects of Independent Variables at Mean Values on Report Health Outcomes[12]

	Excellent Health	Not Limted by Health to do Moderate Activities	Not Limted by Health to Climb Stairs
Damp House	-0.052*** (0.000)	-0.039*** (0.000)	-0.038** (0.028)
Cold House	-0.043*** (0.000)	-0.030*** (0.000)	-0.036*** (0.008)
Heating in all main rooms	0.014* (0.083)	0.009 (0.103)	0.014 (0.238)
Employed	0.063*** (0.000)	0.041*** (0.000)	0.082*** (0.000)
Low Income	-0.030*** (0.000)	-0.021*** (0.000)	-0.048*** (0.000)
Pollution	-0.037*** (0.006)	-0.027** (0.026)	-0.040* (0.069)
NZDEP	-0.008*** (0.000)	-0.004*** (0.000)	-0.013*** (0.000)
No qualification	-0.044*** (0.000)	-0.029*** (0.000)	-0.039*** (0.000)
Age	-0.014*** (0.000)	-0.008*** (0.000)	-0.034*** (0.000)
Maori	-0.020** (0.041)	-0.013* (0.064)	-0.013 (0.395)
Never smoked	0.027*** (0.000)	0.015*** (0.000)	0.029*** (0.003)
Smoker	-0.076*** (0.000)	-0.058*** (0.000)	-0.022* (0.092)
No. of Observations	8,687	8,687	8,687

[12]White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Table 5. Asthma Admissions and Electricity Price Descriptive Statistics; July 2000 – June 2009

	Electricity Price (c/kWh)	**All Admissions**	**Infant Admissions**
Average	18.715	81.793	30.486
Maximum	29.056	310.000	139.000
Minimum	12.606	1.000	0.000
Median	18.513	58.000	23.500
Standard deviation	3.710	65.231	25.345
Skewness	0.354	1.075	1.380
Kurtosis	-0.693	0.289	1.801
First quartile	15.504	32.000	12.000
Third quartile	21.650	119.000	42.250

Table 6. Mapping of Line Businesses to DHB Regions

DHB Domicile Code	DHB Name	Line Business
11	Northland	Top Energy Northpower
21	Waitemata	UnitedNetworks (Waitemata)
22	Auckland	Vector
23	Counties Manukau	Counties Power
31	Waikato	Waipa Networks WEL Networks Powerco (Thames Valley) The Lines Company (Waitomo) The Lines Company (King Country)
42	Lakes	Unison (Rotorua) Unison (Taupo)
47	Bay of Plenty	Horizon Energy Distribution Powerco (Tauranga)
51	Tairawhiti	Eastland Network (Eastland) Eastland Network (Wairoa)
71	Taranaki	Powerco (Hawera) Powerco (New Plymouth) Powerco (Stratford)
61	Hawke's Bay	Unison (Hawke's Bay) Centralines
81	Mid Central	Scanpower Electra Powerco (Manawatu)
82	Whanganui	Powerco (Wanganui)
91&92	Capital and Coast + Hutt Valley	Wellington Electricity Lines (North) Wellington Electricity Lines (South)
93	Wairarapa	Powerco (Wairarapa)
101	Nelson Marlborough	Marlborough Lines Nelson Electricity Network Tasman

111	West Coast	Westpower Buller Electricity
121	Canterbury	Orion NZ MainPower MainPower (Kaiapoi)
		Electricity Ashburton
123	South Canterbury	Alpine Energy
131	Otago	OtagoNet Network Waitaki Aurora Energy (Central Otago Clyde/Crom) Aurora Energy (Dunedin) Aurora Energy (Queenstown)
141	Southland	Electricity Invercargill The Power Company

Table 7. Electricity Price and Electric Heating Use; 2001 and 2006[14]

	Percent of Households with Electric Heating 2001	Number of Households with Electric Heating 2001	Percent of Households with Electric Heating 2006	Number of Households with Electric Heating 2006
Electricity Price (c/kWh)	-0.061*** (0.002)	-4,596.593** (0.031)	-	-149.323** (0.012)
Electricity Price (c/kWh) × 10,000	-	-	0.774* (0.065)	-
Households	-	0.806*** (0.000)	-	1.520*** (0.000)
Observations[13]	20	20	14	14

[13] Annual observations per available regions
[14] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Table 8. Instrumental Variable Regression Results, 2001 and 2006[15]

	Admissions 2001	Admissions 2001	Infant Admissions 2001	Infant Admissions 2001	Admissions 2006	Admissions 2006	Infant Admissions 2006	Infant Admissions 2006
Households with Electric Heating (1000s)	-0.790 (0.848)	-1.422 (0.809)	1.922 (0.596)	0.880 (0.440)	0.079 (0.339)	-0.099*** (0.000)	-2.117*** (0.001)	1.828** (0.011)
Population (1000s)	1.64 (0.176)	-	-	-	-0.019 (0.314)	-	-	-
Households (1000s)	-	5.380 (0.302)	-0.269 (0.933)	-	-	0.072*** (0.000)	3.450*** (0.000)	-
Infant Population (1000s)	-	-	-	3.821 (0.416)	-	-	-	1.887 (0.407)
Observations[16]	20	20	20	20	14	14	14	14

[15] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

[16] Annual observations per available regions

Table 9. The Effects of Electricity Prices on Hospital Asthma Admissions;

DHB-Level Analysis, July 2000 - June 2009[17]

	All Admissions	All Admissions	All Admissions per 10,000 population	All Admissions per 10,000 population	All Admissions per 10,000 population	All Admissions	Log(all admissions)	Log(all admissions)
Electricity price (c/kWh)	6.580*** (0.000)	6.207*** (0.000)	0.0086 (0.860)	-0.0066 (0.895)	0.011 (0.820)	-	-	0.0216* (0.073)
Log(electricity price (c/kWh))	-	-	-	-	-	110.652*** (0.000)	0.423* (0.058)	-
Population (1000s)	0.629*** (0.000)	0.577*** (0.000)	-	-	0.130*** (0.000)	0.593*** (0.000)	0.0052*** (0.000)	0.0053 *** (0.000)
Dependent variable, lagged by one quarter	-	0.023 (0.656)	-	0.149*** (0.000)	0.114*** (0.003)	-	-	-
Observations[18]	720	700	720	700	700	720	720	720

[17] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

[18] Full sample, but loss of one set of regional observations when lagged by one quarter

Table 10. The Effects of Electricity Prices on Hospital Asthma Admissions;

DHB-Level Analysis, July 2000 – June 2009

By Age and Ethnicity[19]

	Infant (0-4 Years) Admissions	Child (5-14 Years) Admissions	Adult (15+ Years) Admissions	Maori Admissions	Pacific Islander Admissions	Other Ethnicity Admissions	Maori Infant Admissions	Pacific Islander Infant Admissions
Electricity price (c/kWh)	3.745*** (0.000)	-0.127 (0.805)	1.072 (0.212)	0.528 (0.419)	0.250 (0.863)	6.210*** (0.000)	0.585 (0.179)	1.58* (0.071)
Population of the respective group (1000s)	1.929** (0.047)	0.584*** (0.000)	0.227*** (0.000)	1.238*** (0.002)	0.607** (0.022)	0.246 (0.176)	1.040 (0.381)	7.553 (0.622)
Observations[20]	720	720	720	720	720	720	720	720

[19] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

[20] Full Sample

Table 11. The Effects of Electricity Prices on Hospital Asthma Admissions;

DHB-Level Analysis, July 2000 – June 2009

Comprehensive Weighted-Average Price Definition[21]

	All Admissions	Infant Admissions	All Admissions (excluding least representative DHBs)[22]	Infant Admissions (excluding least representative DHBs)[22]	All Admissions (excluding least representative observations)[23]	Infant Admissions (excluding least representative observations)[23]
Electricity price (c/kWh) (weighted average)	1.890 (0.240)	2.171** (0.021)	3.324* (0.084)	3.278*** (0.004)	2.138 (0.226)	2.342** (0.024)
Population (1000s)	0.571*** (0.000)	1.521 (0.137)	0.601*** (0.000)	1.328 (0.223)	0.587*** (0.000)	1.812* (0.093)
Observations	720	720	540	540	595	595

[21] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.
[22] DHBs that contain data representing less than 60% of the market are excluded
[23] DHB/quarter cells that contain data representing less than 45% of the market are excluded

Table 12. The Effects of Electricity Prices on Hospital Asthma Admissions;

DHB-Level Analysis, July 2000 – June 2009

Inflation-Adjusted Electricity Price[24]

	National CPI All Admissions	National CPI Infant Admissions	National CPI Child Admissions	National CPI Adult Admissions	Regional CPI All Admissions	Regional CPI All Admissions
Inflation-adjusted electricity price (c/kWh)	6.338*** (0.000)	3.702*** (0.000)	1.215** (0.030)	1.158 (0.174)	-	6.136* (0.075)
Electricity price (c/kWh)	-	-	-	-	6.171* (0.072)	-
Population (1000s)	0.614*** (0.000)	1.806* (0.062)	1.126*** (0.001)	0.287*** (0.000)	-0.144 (0.851)	-0.230 (0.765)
Observations[25]	720	720	720	720	260	260

[24] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

[25] Full sample, except for Regional CPI measure where data was only available from April 2006 – June 2009

Table 13. The Effects of Electricity and Gas Prices on Hospital Asthma Admissions;

DHB-Level Analysis, January 2001 – June 2009[26]

	All Admissions	All Admissions	All Admissions	Infant Admissions	Infant Admissions	Infant Admissions
Electricity price (c/kWh)	1.288 (0.687)	1.430 (0.669)	1.302 (0.696)	0.759 (0.700)	0.739 (0.708)	0.642 (0.747)
Population (1000s)	0.123 (0.718)	0.110 (0.749)	0.122 (0.720)	-2.711 (0.269)	-2.688 (0.285)	-2.626 (0.289)
Gas price (c/kWh) (definition 1)[27]	-	-0.953 (0.770)	-	-	0.137 (0.952)	-
Gas price (c/kWh) (definition 2)[28]	-	-	-0.079 (0.973)	-	-	0.697 (0.666)
Observations[29]	178	178	178	178	178	178

[26] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

[27] Calculated using the lowest price retailer in sub-regions with more than one retailer
[28] Calculated with an un-weighted average price of all available retailers within a sub-region
[29] Gas price data only available for a smaller number of regions and time periods

Table 14. The Effects of Electricity Prices on Hospital Asthma Admissions; DHB-Level Analysis, July 2000 – June 2009

Seasonal and Regional Interactions[30]

	All Admissions	All Admissions	All Admissions	All Admissions
Electricity price (c/kWh)	5.853*** (0.001)	11.45*** (0.000)	8.534*** (0.000)	11.304*** (0.000)
Population (1000s)	0.630*** (0.000)	0.424*** (0.000)	0.413*** (0.000)	0.425*** (0.000)
Quarter 2	-66.186*** (0.000)	-37.336*** (0.000)	-	-38.940*** (0.000)
Quarter 3	-72.828*** (0.000)	-58.627*** (0.000)	-	-62.107*** (0.000)
Quarter 4	-9.330 (0.585)	-17.422*** (0.001)	-	-15.246*** (0.013)
Electricity price × Quarter 2	1.630** (0.036)	-	-	-
Electricity price × Quarter 3	0.937 (0.321)	-	-	-
Electricity price × Quarter 4	-0.220 (0.813)	-	-	-
South Island × Quarter 2	-	-	-	6.555 (0.477)
South Island × Quarter 3	-	-	-	14.212* (0.099)
South Island × Quarter 4	-	-	-	-9.828 (0.290)
South Island	-	21.610 (0.168)	16.025 (0.462)	-
Electricity price × South Island	-	-1.197 (0.154)	-1.484 (0.198)	-
Winter	-	-	-78.290*** (0.000)	-
Electricity price × Winter	-	-	1.932* (0.075)	-
Electricity price × Winter × South Island	-	-	0.356 (0.809)	-

[30] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

South Island × Winter	-	-	10.680 (0.704)	-
Observations[31]	720	720	720	720

[31] Full sample

Table 15. "Straw Man" Analysis: The Effects of Electricity Prices on Hospital Cerebrovascular Admissions;

DHB-Level Analysis, July 2000 – June 2009[32]

	Cerebrovascular Disease All Admissions (Population weighted)	Cerebrovascular Disease All Admissions (No weights)
Electricity price (c/kWh)	-0.058 (0.965)	-0.597 (0.364)
Population (1000s)	0.272*** (0.002)	0.184** (0.020)
Observations[33]	720	720

[32] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

[33] Full Sample

Table 16. The Effects of Electricity Prices on Hospital Asthma Admissions;

DHB-Level Analysis, 2006;

Smoking Status[35]

	All Admissions	All Admissions	All Admissions	All Admissions	Infant Admissions	Infant Admissions	Infant Admissions	Infant Admissions
Electricity price (c/kWh)	16.781*** (0.000)	14.216*** (0.003)	10.856*** (0.003)	11.390*** (0.004)	7.445*** (0.000)	5.640** (0.016)	4.278* (0.056)	4.555* (0.054)
Population (1000s)	0. 474*** (0.000)	0. 514*** (0.000)	0. 527*** (0.000)	0.506*** (0.000)	-	-	-	-
Infant Population (1000s)	-	-	-	-	2.553*** (0.000)	2.836*** (0.000)	2.799*** (0.000)	2.673*** (0.000)
% Current smokers	-	-	630.434** (0.011)	851.384** (0.023)	-	-	266.638* (0.051)	354.611* (0.085)
% Never Smoked	-	-231.343 (0.219)	-	235.445 (0.402)	-	-127.003 (0.220)	-	92.982 (0.559)
Observations[34]	80	80	80	80	80	80	80	80

[34] Data only available for 2006 but includes all regions and quarters
[35] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Table 17. The Effects of Electricity Prices on Hospital Asthma Admissions;

DHB-Level Analysis, 2006;

Economic Deprivation[37]

	All Admissions	All Admissions	All Admissions	Infant Admissions	Infant Admissions	Infant Admissions
Electricity price (c/kWh)	16.781*** (0.000)	13.775*** (0.002)	10.905 (0.003)	7.445 (0.000)	6.003 (0.028)	4.443 (0.068)
Population (1000s)	0.474*** (0.000)	0.475*** (0.000)	0.528 (0.000)	2.553 (0.000)	2.527 (0.00)	2.830 (0.000)
NZDep	-	0.247 (0.247)	-0.009 (0.970)	-	0.104 (0.432)	-0.0329 (0.835)
% Current smokers	-	-	637.063 (0.029)	-	-	291.367 (0.090)
Observations[36]	80	80	80	80	80	80

[36] Data only available for 2006 but includes all regions and quarters
[37] White diagonal robust p-values are reported in parentheses.
*, **, and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

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